Inlet Hydrodynamics under an Intermittent Discharge: Capitol Lake and its Impact on Budd Inlet

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Introduction

West Bay is an area of critical water quality concern in Budd Inlet, chronically exhibiting oxygen levels that approach hypoxic conditions during late summer and fall (Ebbesmeyer et al., 1998). Depressed oxygen levels may be due to nutrient loading, circulation, or a combination of both. Cox et al. (1998) quantified nutrient loadings to Budd Inlet. This paper investigates how the operation of Capitol Lake influences the circulation of West Bay, and whether or not this circulation may be contributing to near-bottom, depressed oxygen levels in West Bay.

Capitol Lake

The present site of Capitol Lake was once an estuary where fresh water from the Deschutes River[1] met the salt waters of Budd Inlet. In 1951, a dam was built under Olympia, Washington's 5th Avenue bridge resulting in the formation of a shallow[2] 270-acre lake. The lake is part of the Capitol campus and is operated by the Washington State Department of General Administration. The lake was originally constructed to serve as a reflection pond for the state capitol. Today however, the lake has become a recreational haven for joggers and picnickers, and a major rearing area for chinook salmon[3].

The Deschutes River drains into Capitol Lake from the south[4]. Two radial gates located in the dam structure regulate releases. Gate operation is automated by a METASYS control system. The operational strategy is to maintain Capitol Lake at a desired level[5]. When the lake rises above the desired level, the gates open as long as the head differential between the lake and the tide is at least one foot. Should the lake drop below the desired level or the lake/tide differential drop below one foot, the gates automatically begin to close. Selected flow statistics for the period from November 1996–August 1997 are presented in Table 1.

Table 1. Capitol Lake Flow Statistics

Description	Flow Study Period 11/5/96 – 9/30/97	Winter 11/5/96 – 1/31/97	Summer 7/1/96 – 9/30/97
Average flow	666 cfs ($18.9\ m^3/sec$)	1,153 cfs ($32.7\ m^3/sec$)	197 cfs ($5.6\ m^3/sec$)
Peak flow	16,184 cfs[6] ($458.3\ m^3/sec$)	16,184 cfs[7] ($458.3\ m^3/sec$)	7,110 cfs ($201.4\ m^3/sec$)
Average flow with the gates open	1,374 cfs ($38.9\ m^3/sec$)	1,905 cfs ($54\ m^3/sec$)	692 cfs ($19.6\ m^3/sec$)
Percentage of time gates open	50 %	60 %	21 %
Average length of time gates open	2.7 hours	4.4 hours	3.2 hours
Gate opening frequency	4.3 times/day	3.3 times/day	1.6 times/day

West Bay

West Bay is the southernmost embayment of Puget Sound. Table 2 lists selected physical characteristics of the bay. An important feature of West Bay is a dredged ship canal that runs along the axis of the bay. At its southernmost end, the ship canal widens into the turning basin as shown in Figure

1. The turning basin is approximately 10 ft (3.1 m) deeper than the ship canal, reaching a maximum depth of approximately 40 feet (12.2 m).

Table 2. West Bay Physical Characteristics

	Non-Metric Units	Metric Units
West Bay length from mouth to Capitol Lake	5500 ft	1.7 km
Width at mouth	2000 ft	0.6 km
Maximum depth	40 ft	12.2 m
Volume at[8]:		
Mean High Water (MHHW)	~ 3.0×10^8 ft^3	~ 8.6×10^6 m^3
Mean Lower Low Water (MLLW)	~ 1.6×10^6 ft^3	~ 4.6×10^6 m^3

Table 3. Deployment Data

Deployment No.	Water Depth Relative to MLLW (m)	Latitude 47^o N (minutes)	Longitude 122^o W (minutes)	Deployment Date	Retrieval Date
1	10.36	3.086	54.367	10/30/96	12/13/96
6	8.53	3.130	54.400	7/18/97	8/13/97
7	8.84	3.074	54.384	8/14/97	10/3/97
8	8.95	3.100	54.491	11/26/97	1/8/98
9	8.56	3.107	54.477	1/8/98	2/20/98

Methods

Currents

West Bay currents were measured using an Acoustic Doppler Current Profiler (ADCP). Through a series of nine continuous deployments, currents were measured from October 30, 1996–February 20, 1998. Current speed and direction were averaged for two-minute intervals every 15 minutes at one-meter depth intervals. Current meter malfunctions occurred during four deployments (deployments 2, 3, 4, and 5), rendering unrecoverable data. Deployment information from the other measurement periods is presented in Table 3. The approximate locations of the ADCP deployments are shown in Figure 1.

Capitol Lake Flows

The Capitol Lake gates lack hydraulic features to allow direct measurement of flow. To overcome this limitation, a level-pool routing approach was adopted for estimating discharge (LOTT Wastewater Resource Management Plan, scheduled completion summer 1998). This approach balances inflows and outflows with storage. A trapezoidal solution was employed to iteratively solve the conservation of mass equation. Inflows consisted of flows received from the Deschutes River and Percival Creek. Deschutes River flows were obtained from USGS gauging station 12080010 located approximately 0.5 miles[9] south of Capitol Lake. Percival Creek flows were estimated with The Precipitation Routing to Stream Model (TPRSM), a continuous hydrologic model which tracks antecedent moisture conditions (LOTT Wastewater Resource Management Plan, scheduled completion summer 1998).

Outflow and storage were calculated in two different ways. The first method relied on lake level data recorded by the METASYS control system. Lake level data was converted to storage with the stage-storage relationship. Outflow was calculated from the solution of the mass conservation equations. The second method employed a calibrated hydraulic model to compute outflow. Storage was calculated from the solution of the mass conservation equations. The second approach was implemented when METASYS control system data was unavailable.

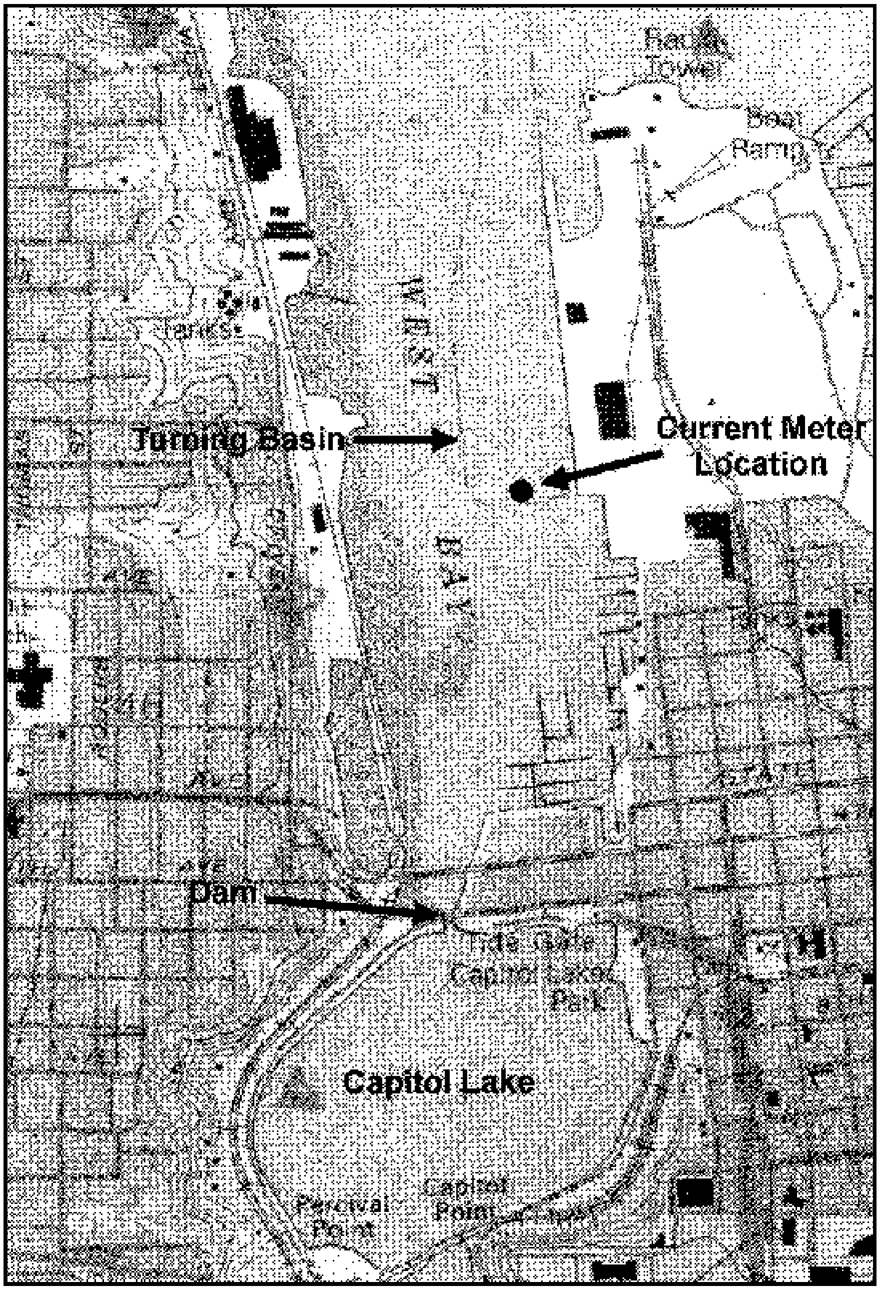

Figure 1. West Bay

Discussion

West Bay currents exhibit a pronounced reaction to discharge from Capitol Lake. Wintertime ADCP deployments revealed a strong, northward-moving, freshwater lens at the surface during releases. During the summertime, the fresh water lens appears to be strongest approximately two meters below the surface. The influence of fresh water releases was typically evident at the ADCP site within 15–30 minutes after gate openings. Velocity structures associated with fresh water releases diminished within a similar time frame. Snapshots in time of the north-south velocity structure during a large release are shown in Figure 2.

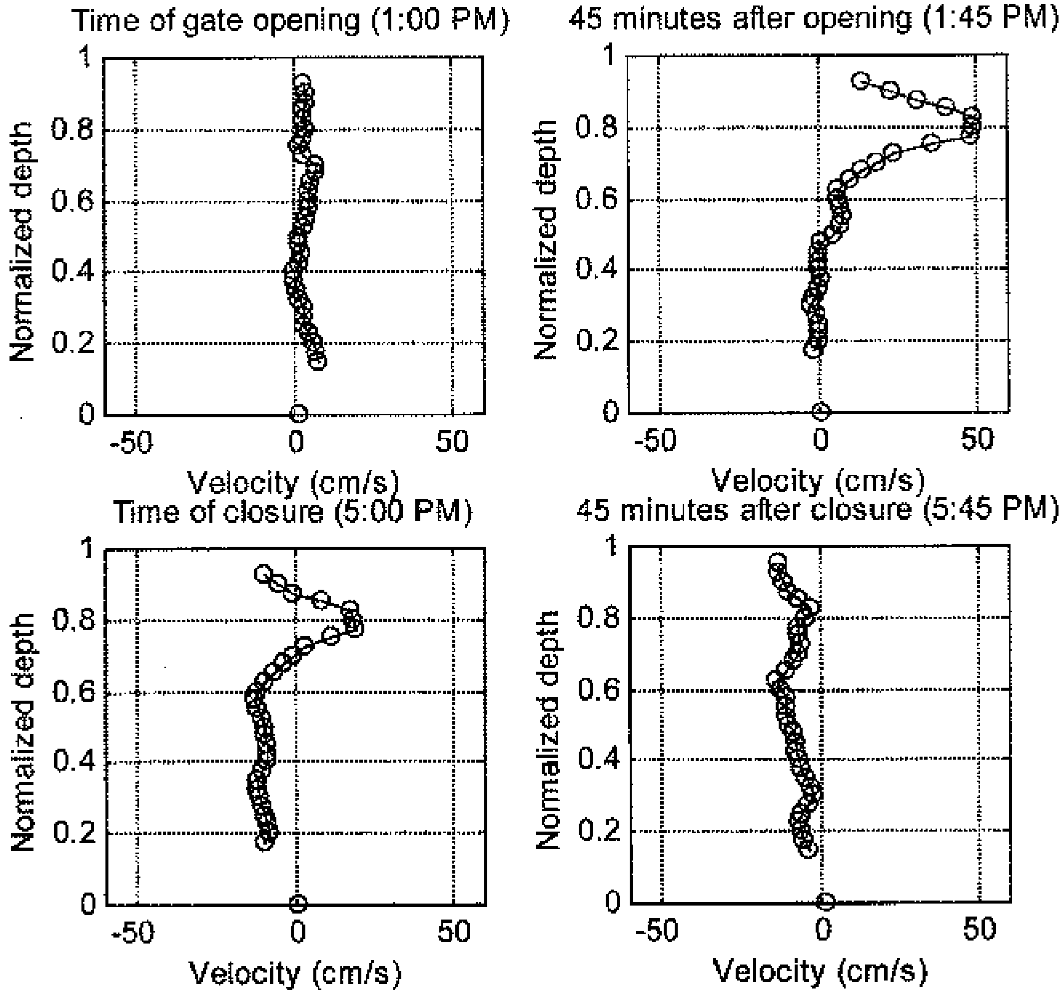

Figure 2. Time-series of north-south velocity during Capitol Lake discharge on July 25, 1997

West Bay salinity concentrations near the sea surface exhibited a strong depression during and after Capitol Lake releases (Figure 3). The background salinity is approximately 25 ppt. During the release concentrations dropped to a minimum of 7 ppt, a reduction of over 70%. Post-release depression of the salinity profile is due to back-washing of fresh water during the flood tide. Flows estimated with the level-pool routing technique correspond well with the salinity profile.

North-south wintertime currents in West Bay exhibit a typical estuarine profile (Figure 4). East-west currents are presented in Figure 5. The vertical scale has been normalized by the water surface elevation. The velocity component near the surface is a result of fresh water flowing northward due to buoyancy and the significant momentum realized in the exchange of potemtial energy for velocity head during lake releases. Strong surface currents induce a return flow at about 0.8D–0.9D, where D is the normalized depth. As would be expected, stronger return flows are correlated with higher average flows from Capitol Lake. The return flow from November 7 – November 14 is barely discernible. During this time Capitol Lake flows averaged 212 cfs (6 m^3/sec). However, in late November and early December after flows increased approximately six times, the return flow became a strong feature.

Wintertime lake releases do not seem to significantly affect north-south currents below 0.5D. Below half the water depth the currents are relatively uniform and almost completely in the southward direction. The one exception is the December 5–December 12 data set which exhibits a weak northward component at about 0.3D. Typical currents in the bottom half of the water column are southward at 1–2 cm/sec.

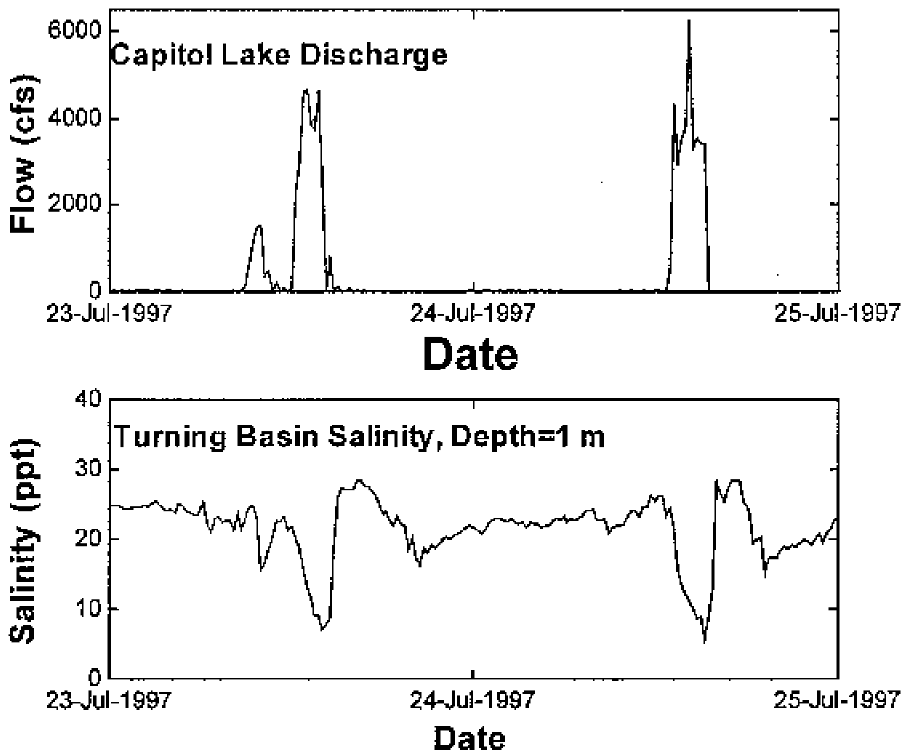

Figure 3. Salinity depression in West Bay during Capitol Lake discharge

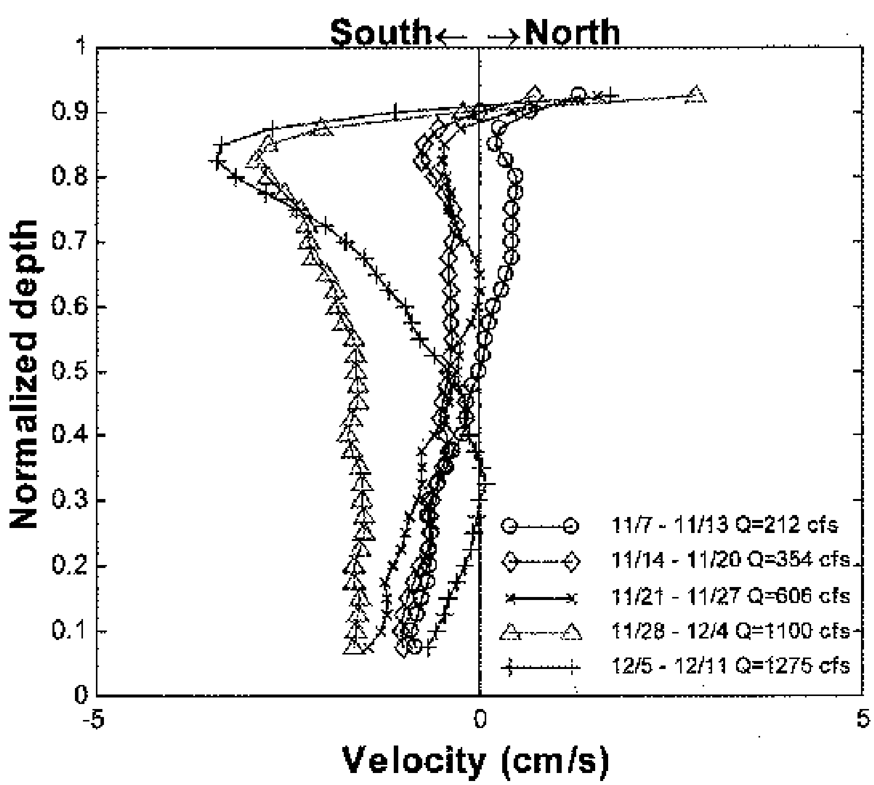

Figure 4. Wintertime seven-day tidally averaged N-S currents

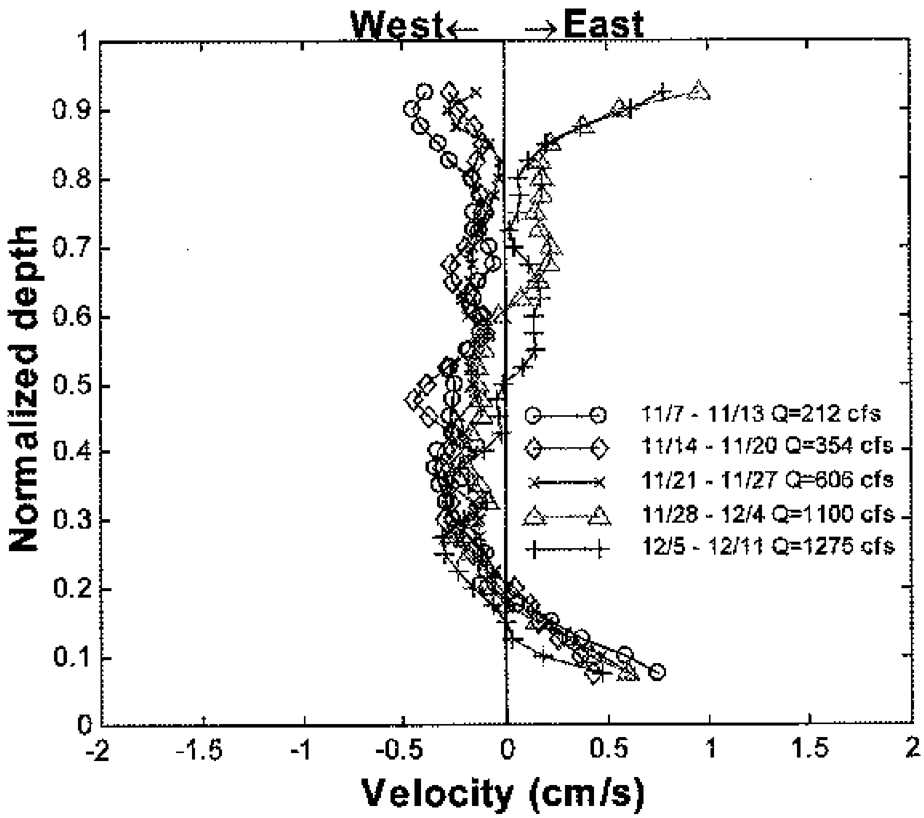

Figure 5. Wintertime seven-day tidally averaged E-W currents

Each year Capitol Lake is partially emptied and then refilled during the summer. Collectively referred to as the drawdown event, it subjects West Bay to one extreme and then the other. The 1997 drawdown occurred from July 22–July 30. During this period the lake was lowered from a normal summertime level of 6.4 ft above mean sea level (MSL) to 3.0 ft below mean sea level over a four-day period. All told, over 750 acre-feet of fresh water were released to West Bay. After the lake level dropped to –3.0 ft MSL, it was refilled to –1.0 ft MSL with salt water. For the next five days, the gates remained closed while the lake was refilled by the Deschutes River to a normal level, at which time normal operation resumed (Washington State Department of Fisheries, 1997).

The drawdown period provides a unique opportunity to observe currents under the influence of strong fresh water releases followed by a period of minimal freshwater release. While the lake refills, West Bay ceases to be an active estuary for several days. North-south currents during and after the drawdown period are shown in Figure 6. The velocity structure during this deployment is not as easily understood as the wintertime structure. Unlike the wintertime two-layer structure, the summer structure appears to have as many as four layers. At this time some of the features are poorly understood. The near-surface velocity approaches zero while the strongest northward velocity is submerged. In addition, a strong southward jet was repeatedly observed periodically around 0.7D throughout the period. This jet is most clearly visible during the period when the gates were closed (July 26–July 30), removing Capitol Lake from the list of potential influences. The near-bottom velocity is approximately 1 cm/sec in the northward direction. This relatively fast velocity (approximately 1 km/day) out of the West Bay is not suggestive of a stagnant body of water. Moreover, it suggests that West Bay approaches hypoxic conditions in spite of significant flushing; however more needs to be known about the cross-channel current variation before any conclusions can be drawn.

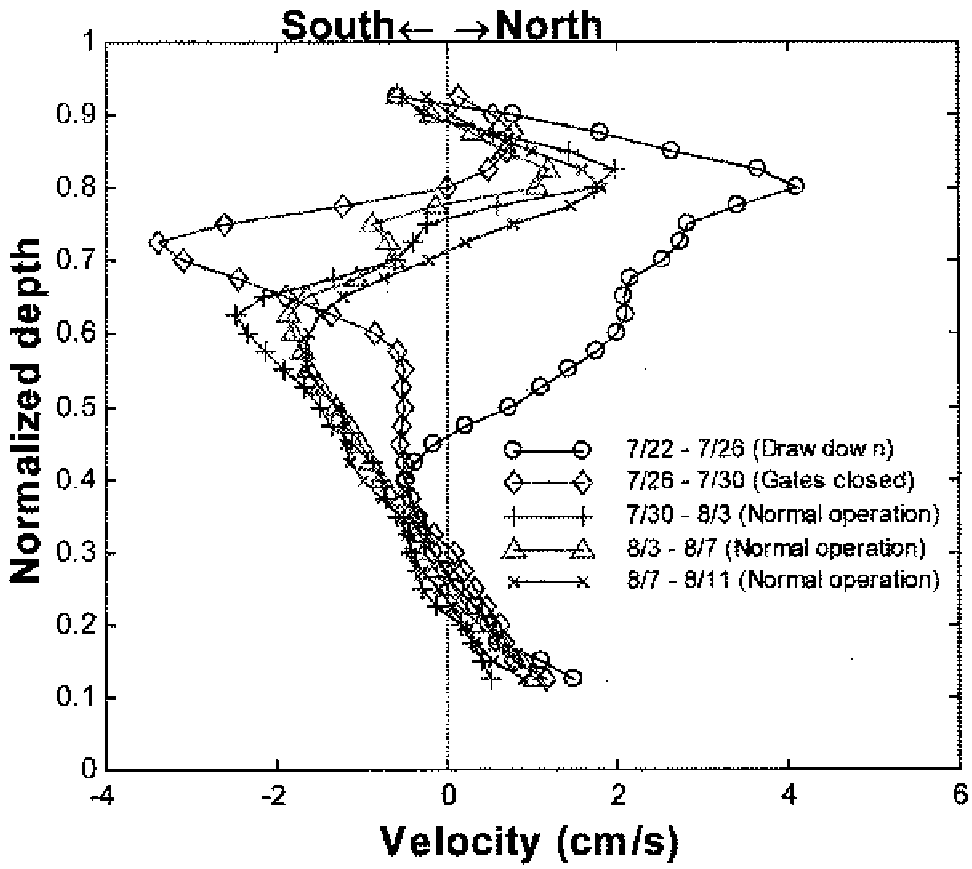

Figure 6. Drawdown period four-day tidally averaged N-S currents

The two most important factors driving West Bay currents are tides and Capitol Lake releases. In order to decompose the freshwater current component, currents under tidal action (July 26–July 30) were subtracted from currents during gate normal operation (July 30–August 11). Tidal currents were also subtracted from currents during lake drawdown (July 22–July 26). The resulting fresh water constituents are shown in Figure 7. Below 0.4D, the influence of Capitol Lake, even during extreme events, has minimal effect on north-south currents.

Acknowledgements

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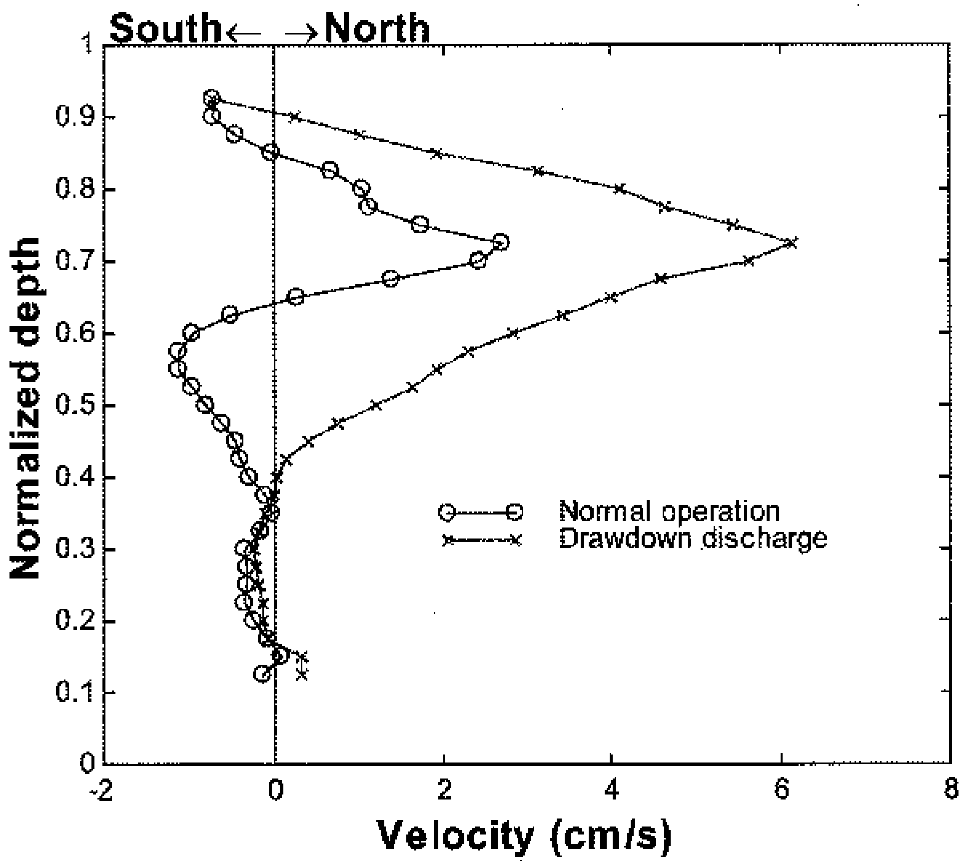

Figure 7. Capitol Lake-Induced N-S Currents

[1] Mean flow based on 34 years of records at USGS gauging station 12079000 is 530 cfs (15 m^3/sec).
[2] Average water depth is 6.5 feet.
[3] The Washington Department of Fish and Wildlife places approximately 5 million fingerlings in the lake each year (The Olympian, October 13, 1997).
[4] Though small compared to the Deschutes River, other sources do contribute flows to the lake. Of these, Percival Creek is the largest (mean flow based on 2 years of records from USGS gauging stations 12078720 and 1278730 is 1.2 m^3/sec). Rainfall, groundwater discharge, and urban runoff are other contributors.
[5] Normal wintertime lake level is 5.8 ft above Mean Sea Level (MSL). Normal summertime lake level is 6.4 ft above MSL. (C. Eikard, personal communication).
[6] Occurred December 30, 1996.
[7] Occurred December 30, 1996.
[8] Albertson et al., 1998
[9] River travel distance.